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# RESEARCH MEMORANDUM

## INFLUENCE OF FUSELAGE-MOUNTED ROCKET BOOSTERS ON FLOW FIELD AT INLET AND ON DIFFUSER PERFORMANCE OF STRUT-MOUNTED ENGINE AT MACH NUMBERS OF 1.8 and 2.0

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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# INFLUENCE OF FUSELAGE-MOUNTED ROCKET BOOSTERS ON FLOW FIELD AT INLET AND ON DIFFUSER PERFORMANCE OF STRUT-MOUNTED ENGINE AT MACH NUMBERS OF 1.8 AND 2.0

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## SUMMARY

The effect of fuselage-mounted rocket boosters on a strut-mounted engine was investigated in the Lewis 8- by 6-foot supersonic wind tunnel at Mach numbers of 1.8 and 2.0 and a Reynolds number of approximately $48 \times 10^6$, based on body length. The boosters were pairs of circular cylinders with conical forebodies mounted on the top and the bottom of the fuselage, and the engine was mounted on a horizontal strut. For the investigation, the boosters were located in two longitudinal positions and fairings were added in the forward position.

The results of the investigation indicated that the boosters in the forward position had the most adverse effect on engine performance. Either moving the boosters aft or adding fairings was effective in reducing the losses in engine mass flow and pressure recovery, but the fairings were more effective.

## INTRODUCTION

An auxiliary power system is required for boosting a ram-jet missile to some operating condition, at which point the ram jets furnish the necessary thrust. In many cases, rockets are used as this auxiliary power system; for supersonic missiles, these rockets may become quite large relative to the missile size. The mounting of these large bodies on the fuselage of a missile may affect the engine performance.

Therefore, an investigation was conducted to determine some of the interference effects on engine performance resulting from rocket boosters mounted on the fuselage. Pairs of rocket boosters were mounted on the top and bottom of a fuselage together with a nacelle engine strut-mounted on the side of the fuselage. The purpose of the investigation was to determine the effect of the boosters on the flow field at the inlet station and the extent to which the engine performance was affected.



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The investigation was conducted in the Lewis 8- by 6-foot supersonic wind tunnel at Mach numbers of 1.8 and 2.0 through a range of angles of attack and mass flow ratios. The Reynolds number of the investigation was approximately $48 \times 10^6$ based on body length.

## APPARATUS AND PROCEDURE

The model investigated in the tunnel (fig. 1) consisted of a body 2692
of revolution with pairs of dummy rocket boosters mounted on the top and bottom of the fuselage and a nacelle-type engine strut-mounted horizontally on the body. The symmetrical fuselage had a length-diameter ratio of 12 and a maximum diameter of 9 inches. The dummy rocket boosters had $60^\circ$ conical noses and cylindrical afterbodies 4.7 inches in diameter and were of arbitrary length. Each pair of boosters was connected by a metal plate across the top of the cones. They were located at two longitudinal stations as shown in figure 1 (hereinafter called boosters-forward and boosters-aft locations) and, with the boosters in the forward position, a fairing (fig. 2(a)) was placed over the nose of the boosters. Photographs showing the fairing on the boosters and the boosters in the aft position are presented in figure 3.

The engine was located $1\frac{1}{2}$ engine diameters from the body center line and was mounted in the horizontal plane (figs. 1 and 3). The diffuser was identical to the modified diffuser of reference 1 with the exception of the inner body aft of the cylindrical portion of the outer shell. Coordinates for the diffuser and the engine dimensions are given in figure 2(b). The mass flow through the engine was controlled by a movable plug mounted from the rear of the body.

A flow survey rake was mounted on the opposite side of the body from the engine and was located longitudinally in the plane of the inlet. Figure 2(c) shows the details of the flow survey instrumentation. Pitot pressure tubes were mounted adjacent to $6^\circ$ flow survey wedges. The entire survey apparatus was shifted vertically to provide a flow survey over the area shown in figure 1(c). Instrumentation for the engines consisted of static pressure rakes located at the diffuser exit and in the combustion chamber, designated in figure 2(b) as stations 3 and A, respectively.

In the reduction of the data from the flow survey apparatus, the measured pitot pressures were corrected for normal shock losses by means of the local Mach numbers as measured by the wedges. As can be seen from figure 1 (front view of the model), shifting the survey apparatus vertically permitted the local Mach numbers and total pressures to be measured at the same points in the flow field. Sidewash angles were measured directly with the wedges and these data were corrected for wedge misalinement or possible free-stream angularity by subtracting the sidewash for the body alone at zero angle of attack from the rest of the data. The mass flow through the engines was computed from the known exit area and the measured combustion-chamber static pressure, assuming choking at the exit area. The ratio of the exit area to the combustion-chamber area determined the combustion-chamber Mach number, which together with the measured static pressure determined the total pressure at station A. This total pressure was assumed to act at the exit station. Total pressure recovery for the diffuser was determined from the known mass flow and the measured static pressure at the diffuser exit (station 3).

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## RESULTS AND DISCUSSION

The characteristics of the flow field at a Mach number of 2.0 are presented in figures 4 to 6. With the boosters located in the forward position (fig. 4(a)), the inlet was immersed in a region of decreased available total pressure. The addition of the fairings to the boosters in the forward position considerably reduced the loss in available total pressure and also confined it to a region close to the body (fig. 4(b)). Moving the boosters aft also reduced the loss in available total pressure although the effects of the boosters on the flow field extended nearly to the inlet (fig. 4(c)).

For the boosters forward, an outwash of the order of $2^{\circ}$ was measured in the vicinity of the inlet (fig. 4(a)). Addition of the fairings completely eliminated the outwash at the inlet and produced a small amount of inwash as indicated in figure 4(b). Moving the boosters rearward also eliminated the outwash produced by the boosters-forward configuration; however, the inwash resulting from the boosters-aft configuration was greater in magnitude than the previously measured outwash (fig. 4(c)). Thus, moving the boosters rearward decreased the total pressure loss, but at the expense of increased sidewash.

For each configuration, it can be seen that a variation of angle of attack has only slight effect on the flow field (figs. 4 to 6). This is evidenced by the fact that the regions of low total pressure and large sidewash are, in general, located in the same position with respect to the inlet throughout the angle-of-attack range. Because of this small angle-of-attack effect, the changes in configuration had the same effect at angles of attack of $3^{\circ}$ and $6^{\circ}$ as at $0^{\circ}$.

For a Mach number of 1.8 and an angle of attack of $0^{\circ}$ (fig. 7), the lowest available total pressure occurred with the boosters in the forward position. Also, as in the case of a Mach number of 2.0, the engines were well outside the low total pressure region when the fairings were on the boosters.

The sidewash contours show that the regions of outflow moved outboard of the body from their positions at a Mach number of 2.0. At a Mach number of 2.0 with the boosters aft, the engine inlet was immersed almost entirely in inflow, whereas at a Mach number of 1.8 a large portion of the inlet was immersed in outflow. The other configurations also showed the same trend. Because of this shifting, the greatest sidewash at the inlet occurred with the boosters in the forward position. Also, greater sidewash was noted with the fairings on at Mach number 1.8 than at Mach number 2.0.

A comparison of engine mass flow and pressure recovery for various configurations at zero angle of attack for the two Mach numbers is presented in figure 8. At a Mach number of 2.0, the boosters in the aft position and the forward position with fairings had a small but measurable effect on mass flow and pressure recovery. The boosters in the forward position, however, reduced the pressure recovery and the maximum mass flow ratio and completely eliminated the stable range.

At a Mach number of 1.8, the boosters in the aft position caused a relatively greater decrease in mass flow and pressure recovery than at a Mach number of 2.0. This is due probably to the fact that the shock off the boosters lay farther forward at a Mach number of 1.8 than at a Mach number of 2.0. Also, with the boosters forward, there was a stable operating range at a Mach number of 1.8 where there was none at a Mach number of 2.0.

The engine characteristics for all configurations at a Mach number of 2.0 are presented in figure 9. With the boosters off, the pressure recoveries and mass flows were nearly the same as those obtained with the engine alone (reference 1) except that the stable operating range was reduced at angle of attack.

Mounting the boosters on the fuselage in the forward position reduced both the maximum total pressure recovery and the mass flow ratio of the diffuser. Also, at $0^\circ$ and $3^\circ$ angles of attack, the stable subcritical range obtained with the boosters-off configuration was entirely eliminated. The lack of stable subcritical range (as contrasted to the stable range obtained for other configurations at these angles of attack) is believed to result from the region of low available total pressure located in a restricted section near the cowl lip, as shown in the flow surveys of figures 4(a) and 5(a), since, when the low total pressure region receded from the lip at $6^\circ$ angle of attack, a small stable subcritical range was obtained. Comparison of the sidewash contours for the angle-of-attack range and among the three configurations indicates that sidewash probably did not cause the diffuser instability. With the boosters forward, increasing the angle of attack from $3^\circ$ to $6^\circ$ increased the mass flow ratio and provided a limited stable subcritical range but decreased the total pressure recovery. Considering the flow survey (figs. 5(a) and 6(a)), it appears possible that the increased mass flow ratio resulted from an increase in available total pressure and a decrease in sidewash. Although not presented, the Mach number in the vicinity of the inlet was also lower for an angle of attack of $6^{\circ}$ than for $0^{\circ}$ and $3^{\circ}$. It is also possible that the increase in mass flow could have resulted from downwash changes.

With the fairings on the boosters, the only characteristic that varied with angle of attack was the stable operating range. This variation, which was a decrease of stable subcritical range with an increase of angle of attack, was apparently not the result of changes in available total pressure or sidewash but is possibly a function of downwash.

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With the boosters in the aft position little change was noted in the mass flow or pressure recovery as the angle of attack was increased from $0^{\circ}$ to $3^{\circ}$. A considerable decrease, however, resulted from an increase in the angle of attack from $3^{\circ}$ to $6^{\circ}$. Apparently this variation in diffuser characteristics with angle of attack cannot be attributed to either the available total pressure or the sidewash, since, from figures 4(c), 5(c), and 6(c), little change is noted in these quantities through the angle-of-attack range. It can also be seen that for angles of attack of $0^{\circ}$ and $6^{\circ}$ the mass flow and pressure recovery were reduced approximately 2 percent from the $0^{\circ}$ and $6^{\circ}$ values for the boosters-off configuration. It thus may be concluded that some other stream variable, such as downwash or Mach number, favorably influenced the diffuser at an angle of attack of $3^{\circ}$ but not at $0^{\circ}$ or $6^{\circ}$.

## SUMMARY OF RESULTS

An investigation to determine the effects of fuselage-mounted rocket boosters on the flow field at the inlet and on the diffuser performance of a strut-mounted engine at Mach numbers of 1.8 and 2.0 was conducted in the Lewis 8- by 6-foot supersonic wind tunnel. The boosters, which were pairs of circular cylinders with conical forebodies, were located on the top and bottom of the fuselage. They were investigated in two longitudinal positions and with fairings.

The following results were obtained:

1. At a Mach number of 2.0, the boosters in the forward position had the effect of immersing the inlet in a region of low available total pressure. Placing fairings on the boosters or moving them aft without fairings tended to reduce the loss in available total pressure. However, moving the boosters aft increased the available total pressure at the expense of increased sidewash. At a Mach number of 1.8, the greatest loss in available total pressure and the largest sidewash were obtained with the boosters forward. Adding fairings to the boosters was the most successful way of reducing these losses.

2. At both Mach numbers the greatest losses in mass flow and total pressure recovery of the engine were obtained with the boosters in the forward position. The most effective means of reducing these adverse effects was the placing of fairings over the nose of the boosters. Moving the boosters aft was also helpful but not so effective as the fairings.

3. Angle of attack had only a slight effect on the flow field characteristics for each configuration.

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REFERENCE

1. Obery, L. J., and Krasnow, H. S.: Influence of a Canard-Type Control Surface on the Internal and External Performance Characteristics of Nacelle-Mounted Supersonic Diffusers (Conical Centerbody) at a Rearward Body Station for a Mach Number of 2.0. NACA RM E52F16, 1952.

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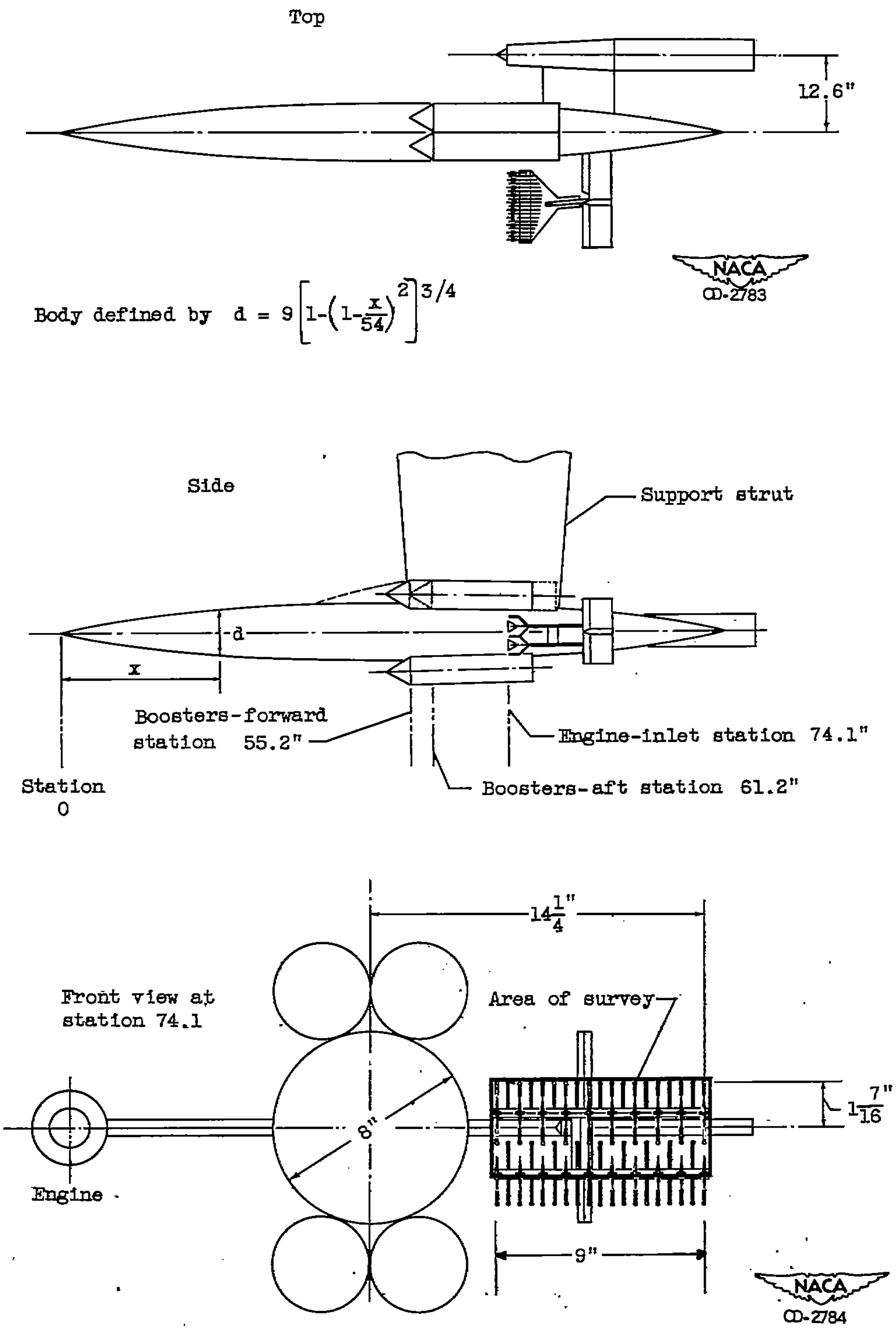
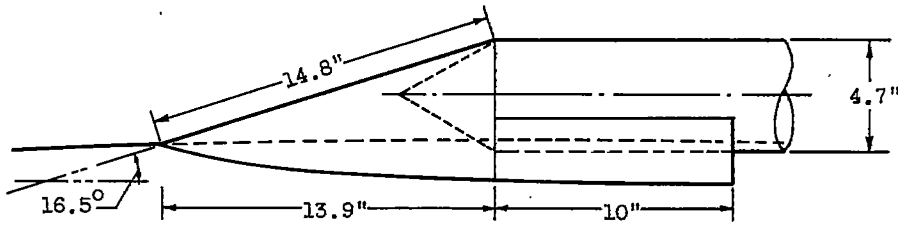



Figure 1. - Sketch of model showing location of various components.




(a) Fairing.

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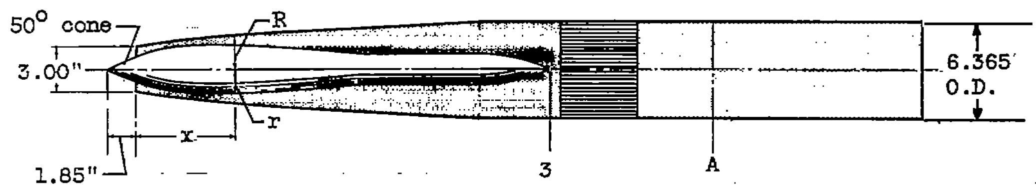
| x, in. | 0 | 0.15 | 0.40 | 0.65 | 1.15 | 1.65 | 2.15 | 2.34 | 3.15 | 4.15 | 6.90 | 7.65 | 9.65 | 11.06 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| R, in. | 1.50 | 1.54 | 1.60 | 1.66 | 1.74 | 1.79 | 1.84 | 1.85 | ←Straight taper to→ | | | | | 2.48 |
| r, in. | 0.86 | 0.93 | 1.03 | 1.13 | 1.26 | 1.33 | 1.38 | 1.40 | 1.46 | 1.51 | 1.56 | 1.54 | 1.43 | 1.31 |

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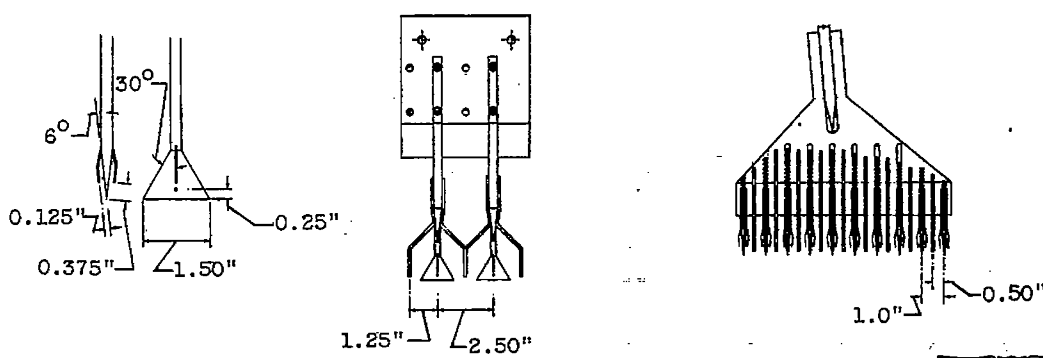
(b) Engine.

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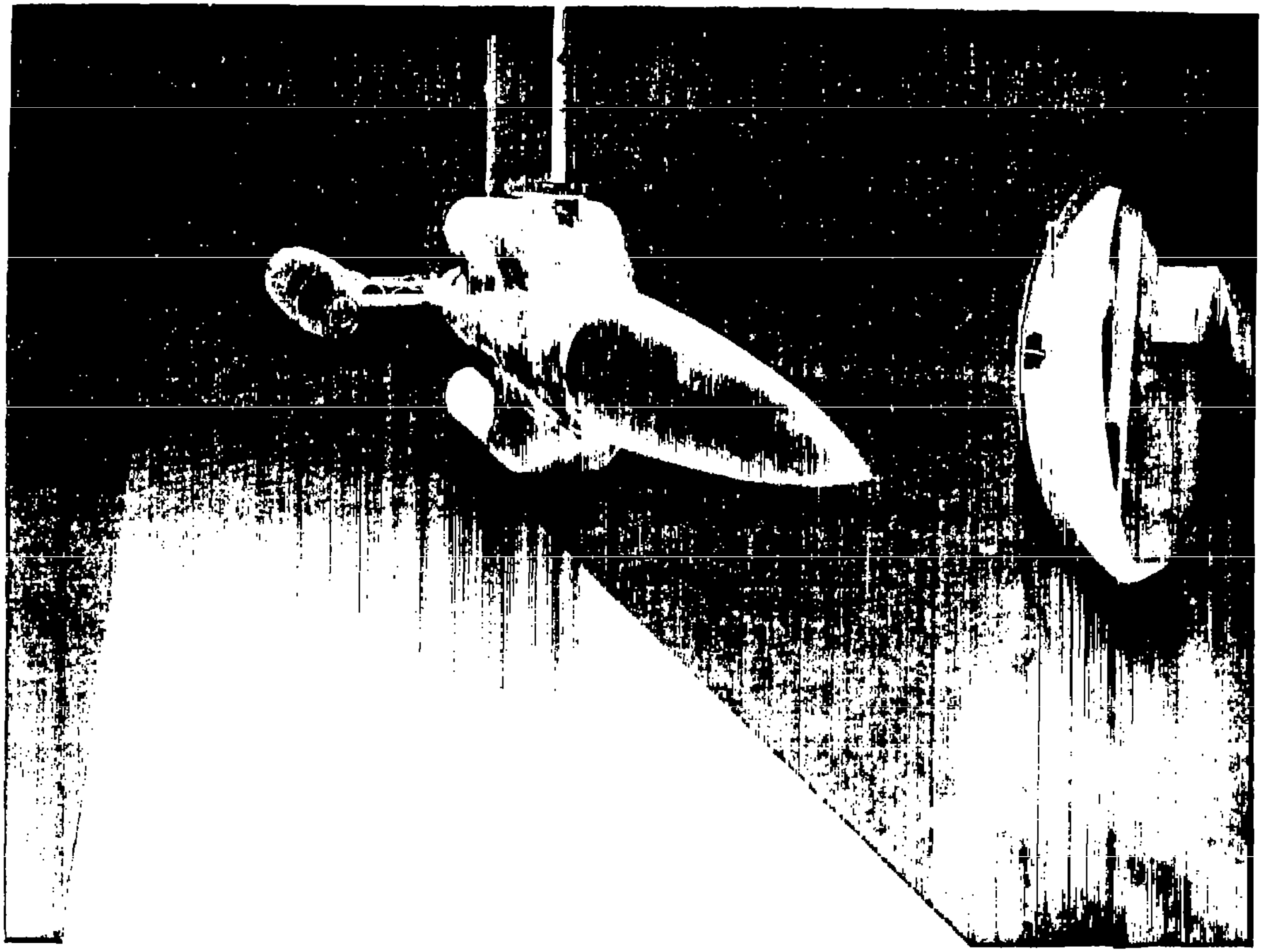
(c) Survey rake.

Figure 2. Details of fairing, engine, and survey rake.



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(a) Boosters forward with fairings.

Figure 3. - Photographs of model mounted in tunnel.

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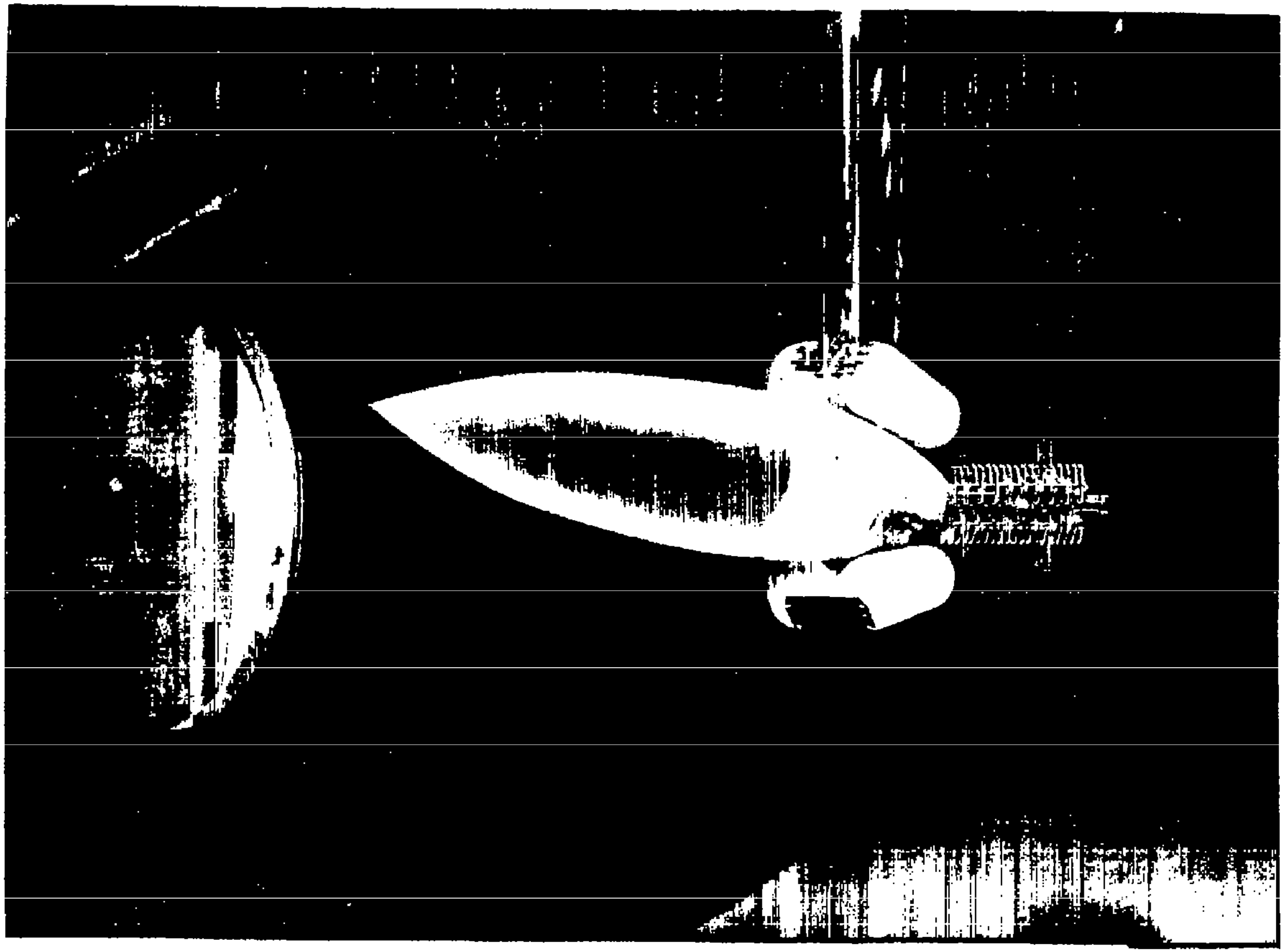

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(b) Boosters aft.

Figure 3. - Concluded. Photographs of model mounted in tunnel.

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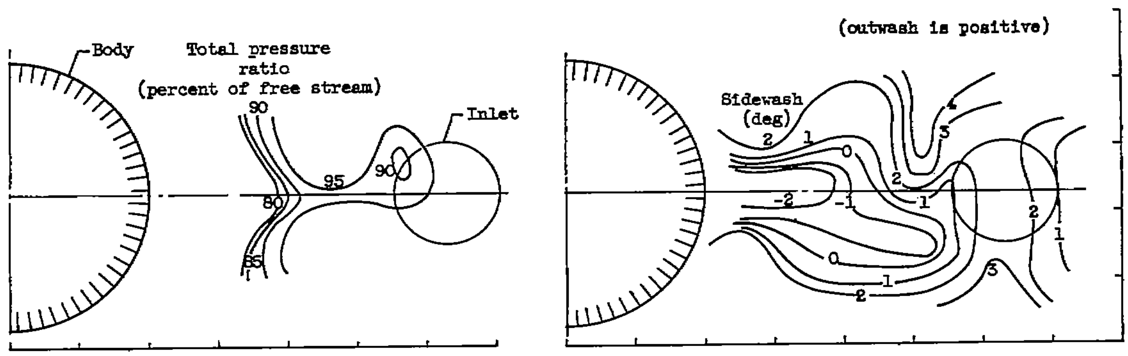
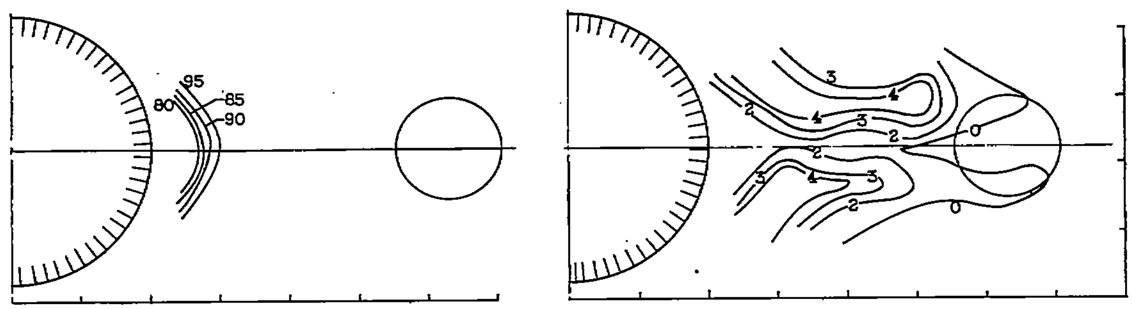
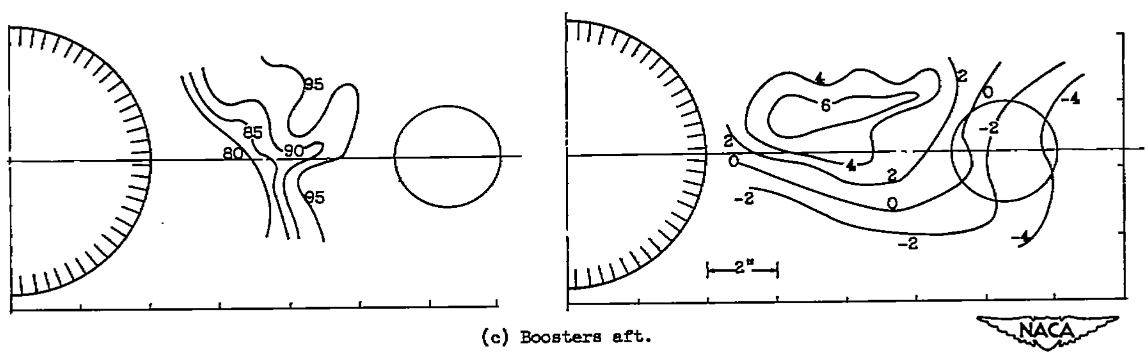



(a) Boosters forward.



(b) Boosters with fairings.




(c) Boosters aft.

Figure 4. - Contours of total pressure ratio and sidewash for three configurations. Angle of attack, 0°; Mach number, 2.0.

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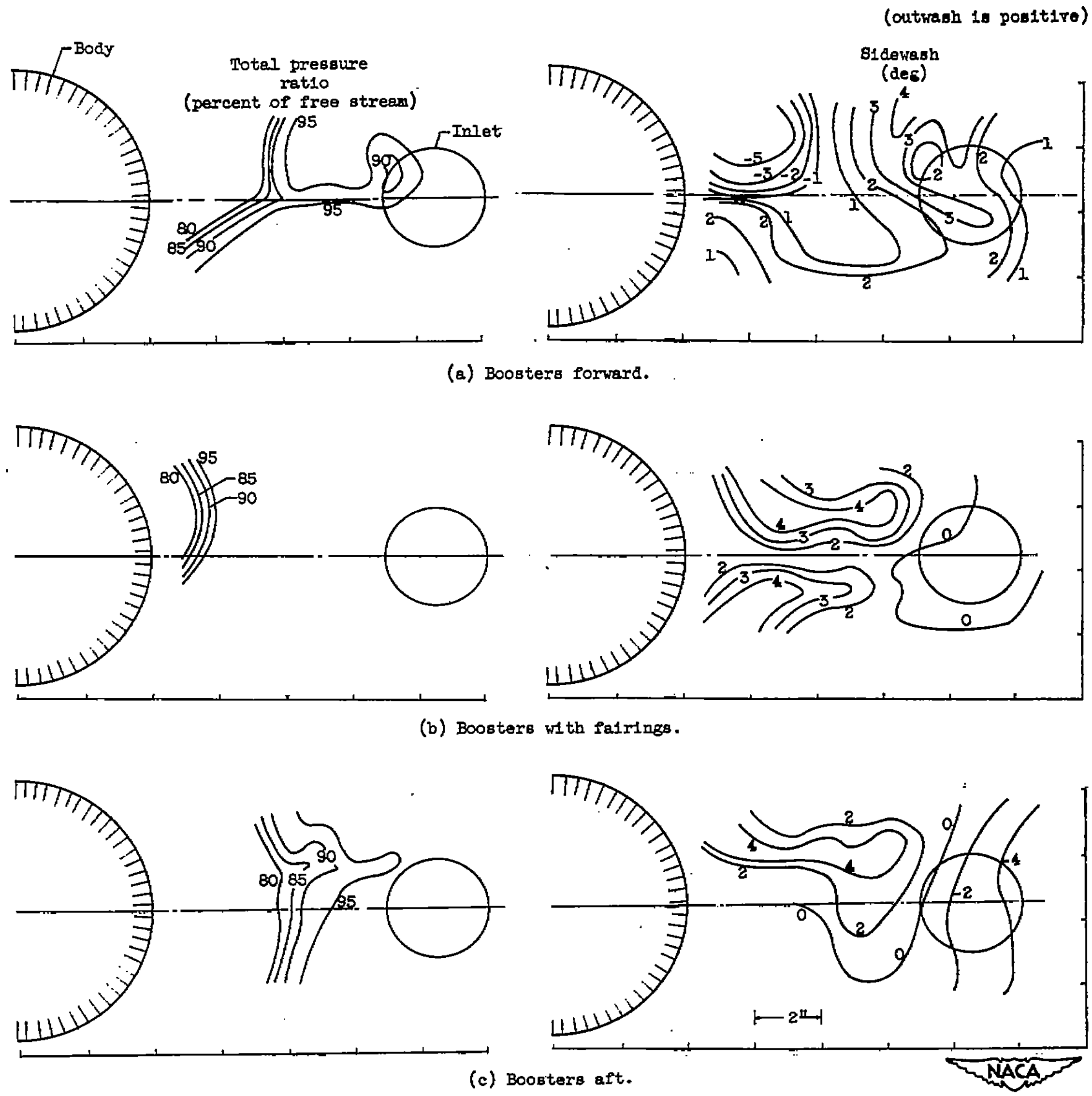


(a) Boosters forward.

(b) Boosters with fairings.

(c) Boosters aft.

Figure 5. - Contours of total pressure ratio and sidewash for three configurations. Angle of attack, 3°; Mach number, 2.0.

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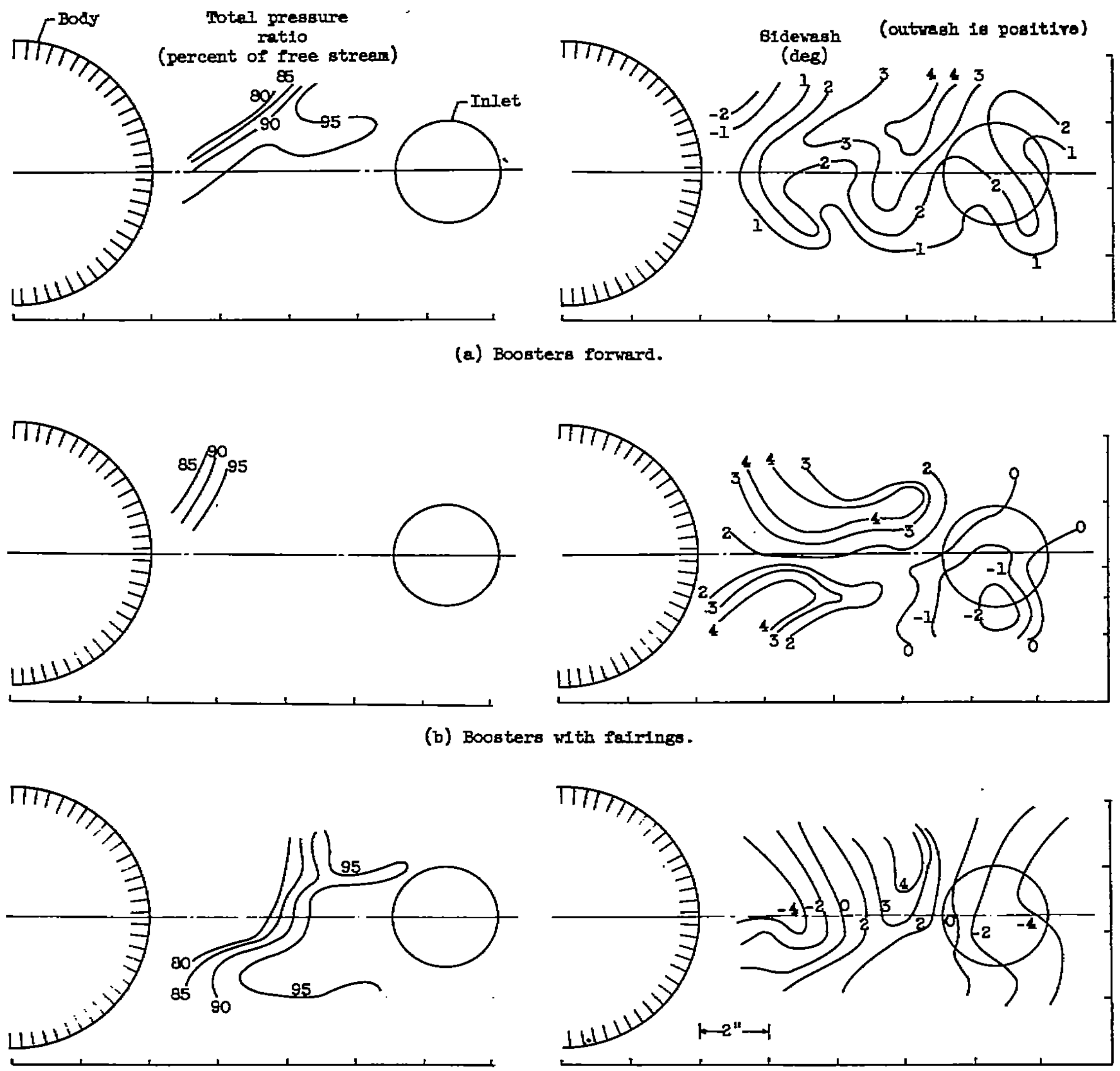


(a) Boosters forward.

(b) Boosters with fairings.

(c) Boosters aft.

Figure 6. - Contours of total pressure ratio and sidewash for three configurations. Angle of attack, 6°; Mach number, 2.0.

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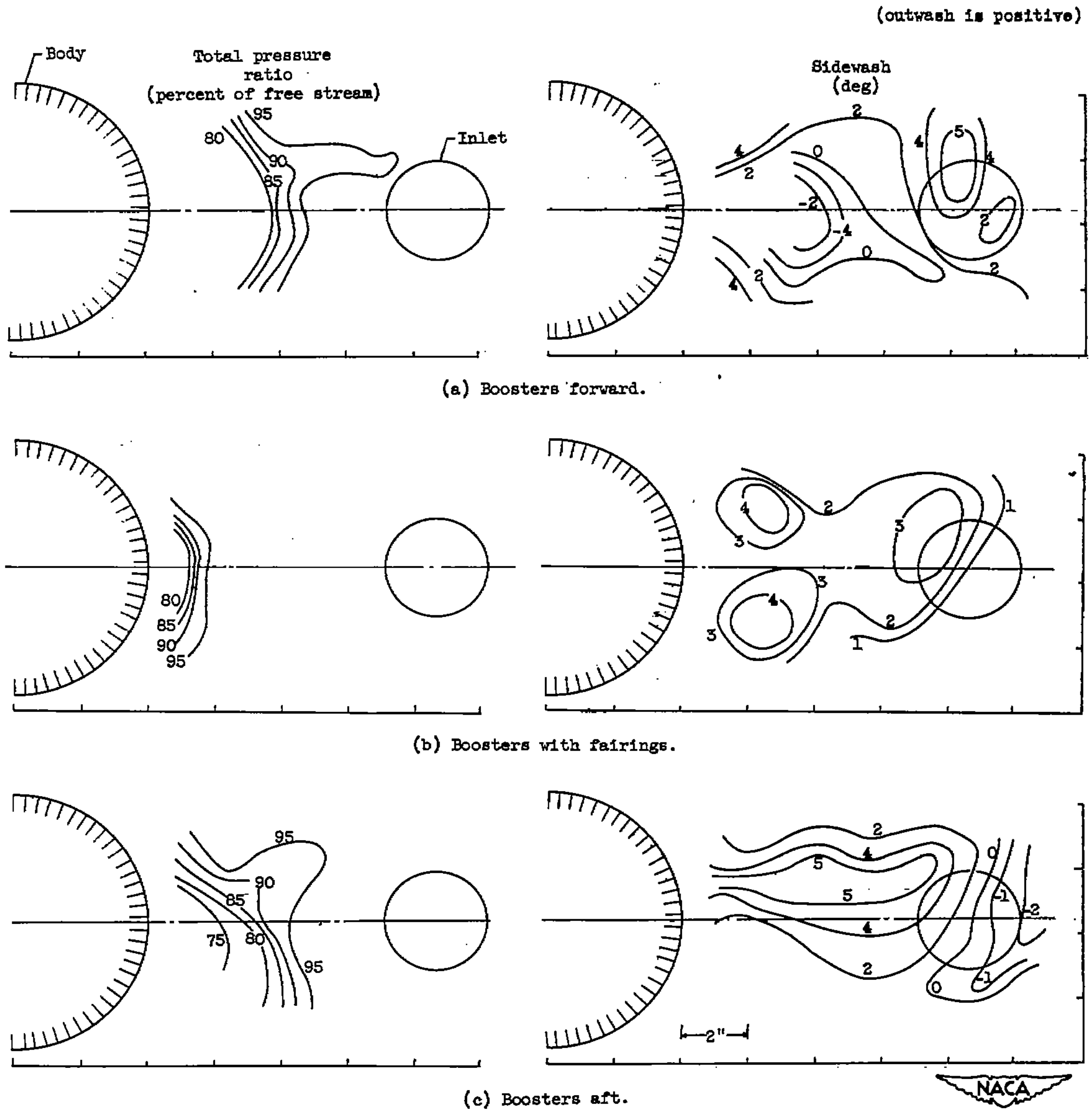


Figure 7. - Contours of total pressure ratio and sidewash for three configurations. Angle of attack, $0^{\circ}$; Mach number, 1.8.

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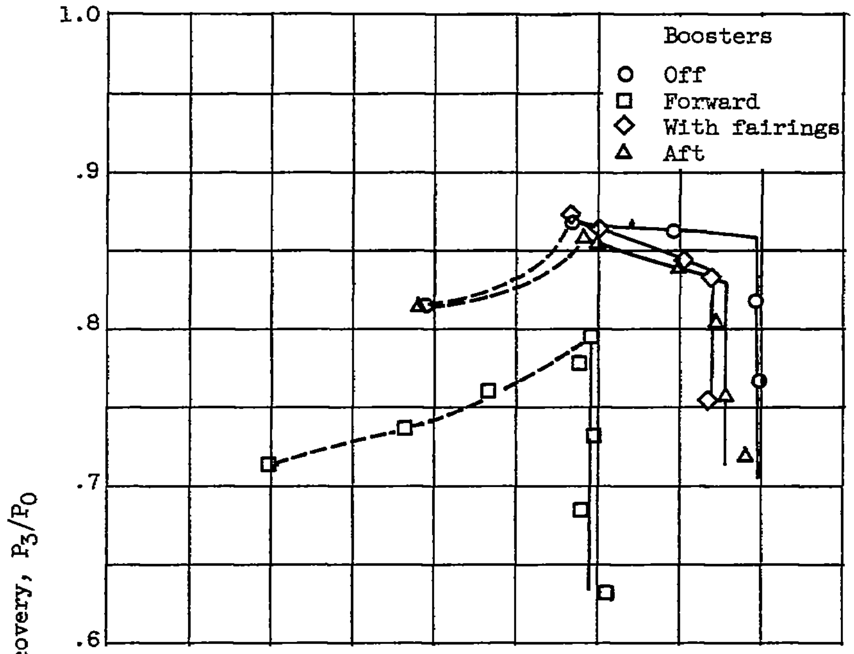
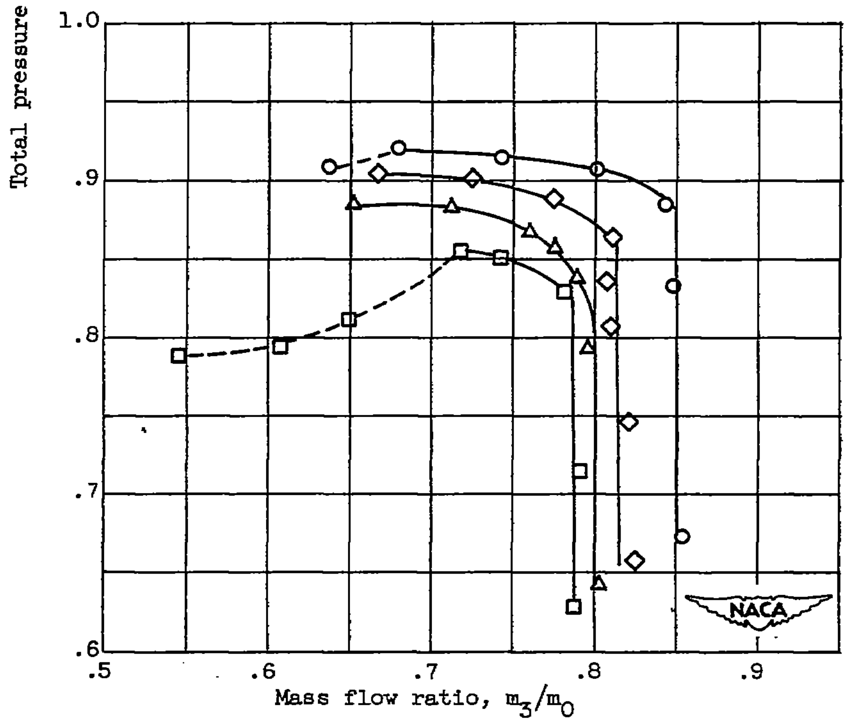



(a) Mach number, 2.0.




(b) Mach number, 1.8.

Figure 8. - Variation of total pressure recovery with mass flow ratio for four configurations at two Mach numbers. Angle of attack, 0°.

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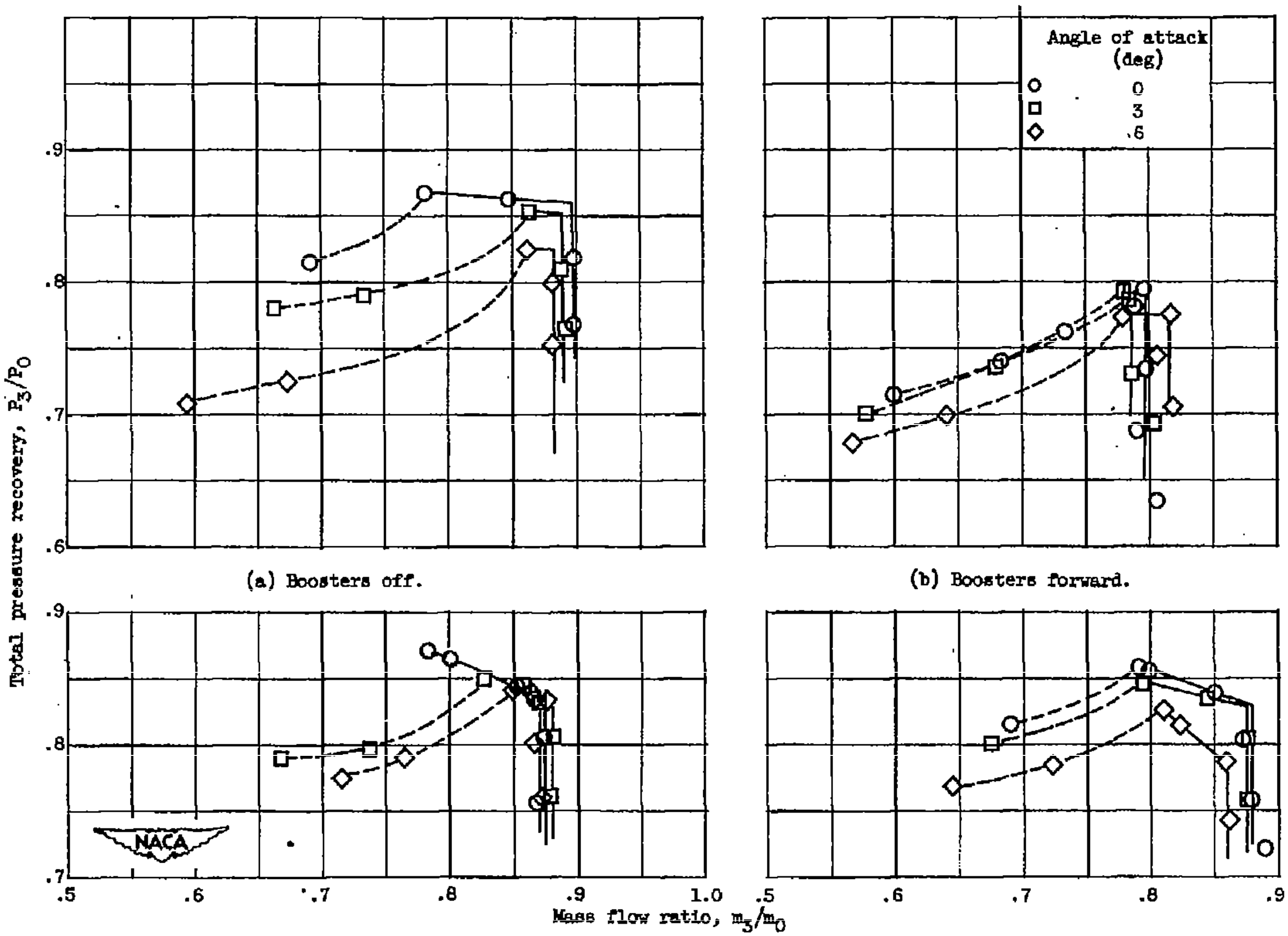


(a) Boosters off.

(b) Boosters forward.

(c) Boosters with fairings.

(d) Boosters aft.

Figure 9. - Variation of total pressure recovery with mass flow ratio for four configurations at several angles of attack. Mach number, 2.0.

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